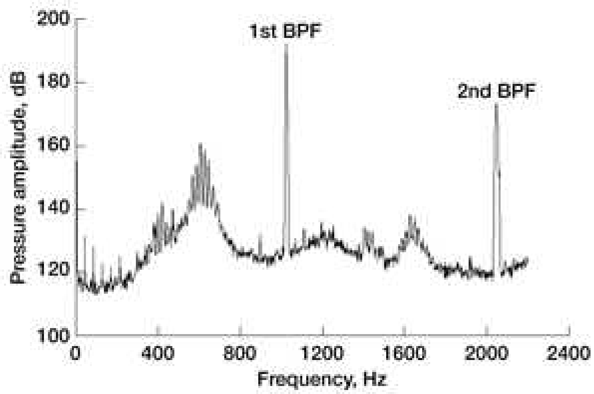
Mechanisms of Rotating Instability in Axial Compressors Investigated

Rotating instability is a phenomenon that occurs in the tip flow region of axial compressor stages during stable operation. It can be observed in highly staggered rotors with significant tip clearance and is strongest at high-load operating points where the characteristic levels off. In this condition, the single-stage fan under investigation radiates an audible, whistling tone, and wall pressure spectra in the vicinity of the rotor disk exhibit nonrotational components. The following graph shows the spectrum of static pressure at a point on the endwall near the leading edge. A hump appears at roughly half of the blade passing frequency (BPF) and is characteristic of rotating instability.



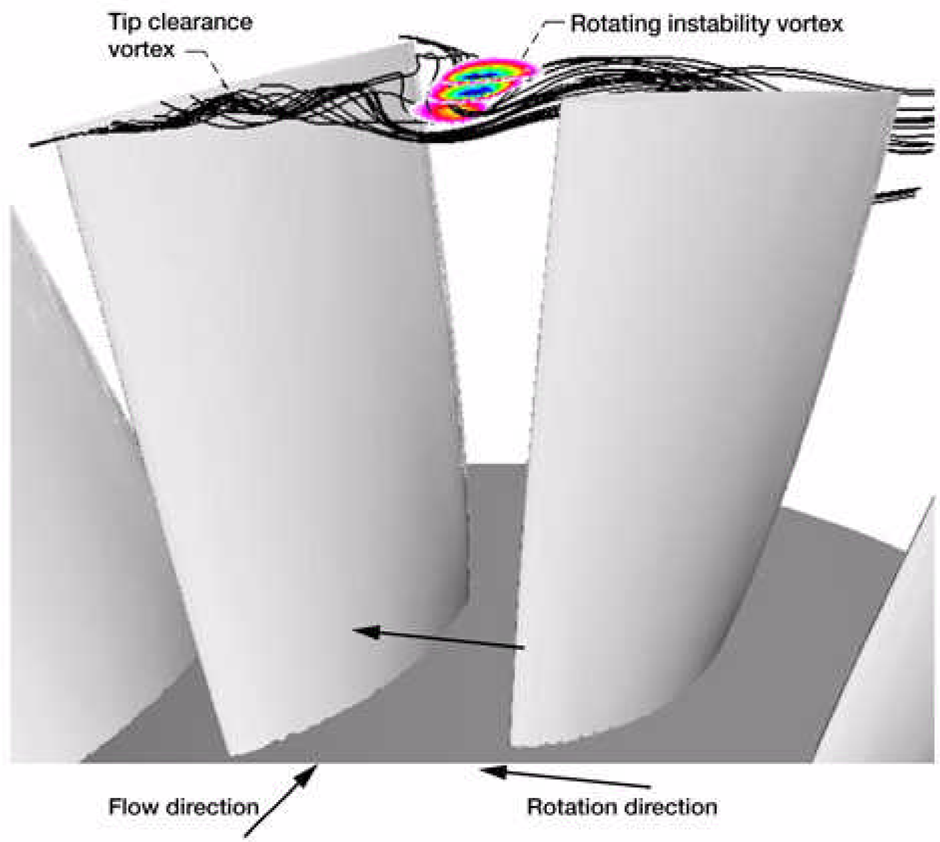
Wall pressure spectrum with rotating instability components; blade passing frequency, BPF, 1024 Hz.

Long description of figure 1 This plot shows the pressure spectrum for operation of the test compressor at a blade passing frequency of 1024 Hz. The vertical axis is pressure amplitude ranging from 100 to 200 dB, and the horizontal axis is frequency from 0 to 2200 Hz. Spikes in amplitude are observed at 1024 and 2048 Hz, corresponding to one and two times the blade passing frequency. A wider, lower-amplitude peak, or hump, in pressure amplitude is seen near 600 Hz, or roughly one-half the blade passing frequency. This hump is characteristic of rotating instability.

.

A computational model was developed at the NASA Glenn Research Center to investigate the mechanism behind this phenomenon. A three-dimensional steady Navier-Stokes code that has been successfully tested for a wide range of turbomachinery flows was modified to execute a time-accurate simulation of the full annulus of the compressor. At the inlet of the computational domain, the total pressure, total temperature, and two velocity components are specified. Since no unsteady measurements of static pressure or other flow variables were available downstream of the rotor, circumferentially averaged static pressure was specified on the shroud at the outlet of the computational domain.

A three-dimensional view of the vortex from the numerical model is shown in the following figure. Particle traces released near the leading edge tip have rolled up to illustrate the tip clearance vortex. Flow near the trailing edge is pushed forward by the axially reversed flow. It then interacts with the tip clearance flow and the incoming flow and results in the rotating instability vortex, the core of which is illustrated by total pressure shading on planes located successively downstream. The rotating instability vortex is formed periodically midway between the blades and moves toward the pressure side of the passage. The unsteady behavior of this vortex structure is the main mechanism of the rotating instability shown in the graph. The numerical model can be used to detect any possible occurrence of rotating instability when the tip clearance increases during engine service.



Structure of the instantaneous flow field including the tip clearance vortex and rotating instability vortex.

Long description of figure 2 This figure shows a three-dimensional view of the blade surfaces near the tip. Particle traces released near the leading edge tip roll up to illustrate the tip clearance vortex. Total pressure shading on planes located successively downstream illustrate the core of the rotating instability vortex. This vortex forms because of interactions between the incoming flow, the tip clearance flow, and reversed flow from the trailing edge region. Unsteady behavior of this vortex structure is the main mechanism of rotating instability.

.

References

1. Hah, C.: A Navier-Stokes Analysis of Three-Dimensional Turbulent Flows Inside Turbine Blade Rows at Design and Off-Design Conditions. J. Eng. Gas Turbines Power, vol. 106, no. 3, 1984, pp. 421-429.

2. März, Joachim; Hah, Chunill; and Neise, Wolfgang: An Experimental and Numerical Investigation Into the Mechanisms of Rotating Instability. Trans. ASME J. Turbomachinery, vol. 124, no. 3, 2002, pp. 367-375.

Glenn contact: Dr. Chunill Hah, 216-433-6377, Chunill.Hah-1@nasa.gov
Author: Dr. Chunill Hah

Headquarters program office: OAT
Programs/Projects: Propulsion and Power, SEC